

Closing the loop on SEI and ISC for interferometer analysis





SEI: seismic systems, SUS: suspensions ISC: interferometer sensing and control ASC: alignment sensing and control



L Barsotti et al 2010 Class. Quantum Grav. 27 084026 With LHO LSC, ASC and DARM noise budget curves





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Example: ASC in Fabry-Perot cavity

- Auxilliary controls noises of high-finesse cavities suffer from a curse
 - The relative sensitivity of length and alignment scales with finesse
- This naturally entails that if length is quantum-noise limited

<u>The alignment D.O.F. should never</u> <u>have control in-band</u>

Alignment is also usually sensed from pick-offs which further reduces relative sensitivity



McCuller, GWADW May '21

* valid for cavities with $2 < \phi_{\rm Gouv} < 2\pi - 2$

Example: ASC in Fabry-Perot cavity

 c_0

1000ppm input coupler:

 $rac{4}{T}\sim 4000$ (bad factor)

300m cavity (w~10mm) with 1uRad of RMS misalignment:

 $\frac{k\omega}{2} \theta_{\rm RMS} \sim .03$ (good factor)

1000x more power in sensing than (backscatter driven) length:

$$rac{1}{\sqrt{1000}}\sim .03$$
 (good factor

$$|c_{00}| = \sqrt{\frac{4}{T}} |b_{01}| \cdot k\omega \delta\theta \approx \frac{4}{T} \cdot \frac{k\omega}{2} \theta_{\rm RMS} \cdot |c_{01}|$$

* valid for cavities with
$$2 < \phi_{\rm Gouy} < 2\pi - 2$$

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10x safety and 6db sqz: 20x (bad factor)

ASC Loop needs to roll off by: $20 \cdot 4000 \cdot .03 \cdot .03 \approx 75$

assuming no other DC misalignment, and that ASC is guantum-limited in its sensing

To summarize what all you need

- Ground noise
- SEI performance model
 - appropriately blended control
- SUS model
 - appropriately damped control
- Electronics Models
 - Margin to quantum limit

many of these steps require a human to design fiducial/actual loop models at each iteration

- Interferometer Model, with control
 - length sensitivity
 - RMS sensitivities
 - bilinear sensitivities
- Contamination of ASC/LSC error points (IFO + SUS + SEI model)
 - Vertex
 - input-output optics
 - VCO and Laser noises
- Understanding of margins, discrepancies
 - the ASC residual is not the RMS
 - nor is the alignment dither system residual (apparently, study ongoing)

Model Framework in Statespace



Model Framework in Statespace



Seismic Model Internals



Seismic sensing PSD-like

LQE/Kalman Seismic Toy Example



LQE/Kalman Seismic Example



LQE/Kalman Seismic Example



LQE/Kalman with Whitening



LQE/Kalman with Whitening



LQE with AAA-fit (optimal?) Weighting





The big ideas

- Fitting can now create the needed root-PSD noise, weight, plant filters.
- Essentially building these models to study LIGO, not yet in this framework
- Such models, in some framework, are needed for LSC/ASC design requirements
- If done in statespace, it seems possible to remove all design freedom of the control system → inclusion as fundamental noise curves
- Speculation: If the "aspirational optimum" sensing blend curves are saturated at each point, no *further information is available* → AI and bilinear subtraction will not help to surpass limits implied by those curves
- We can thus establish performance bounds given as-built or as-designed configurations
 - Find how near current-gen is from the as-built bounds.